Main Injector H^- Injection

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Outline

- **Goals & Strategy of Injection Design R & D**
- **MI H- Injection System**
- **Conclusions**

Goals of Injection Design R&D

- **Produce a technically sound 8 GeV H- transport and injection design for the utilization of a 2 MW Superconducting Linac as an injector into the Main Injector in support of the High Intensity Neutrino Source (HINS) Program**
- **If there are delays in the effort “fast track” to the ILC due to either cost or R&D issues, we want to have all technical issues regarding transport & injection resolved so that construction could proceed rapidly.**
- **Generate a detailed Design Report and cost estimate for all required systems**

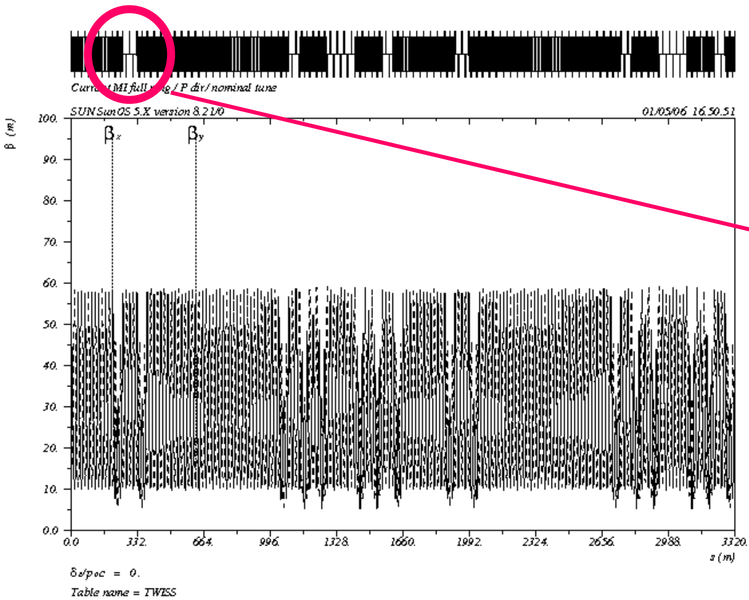
Strategy for Injection Design R&D

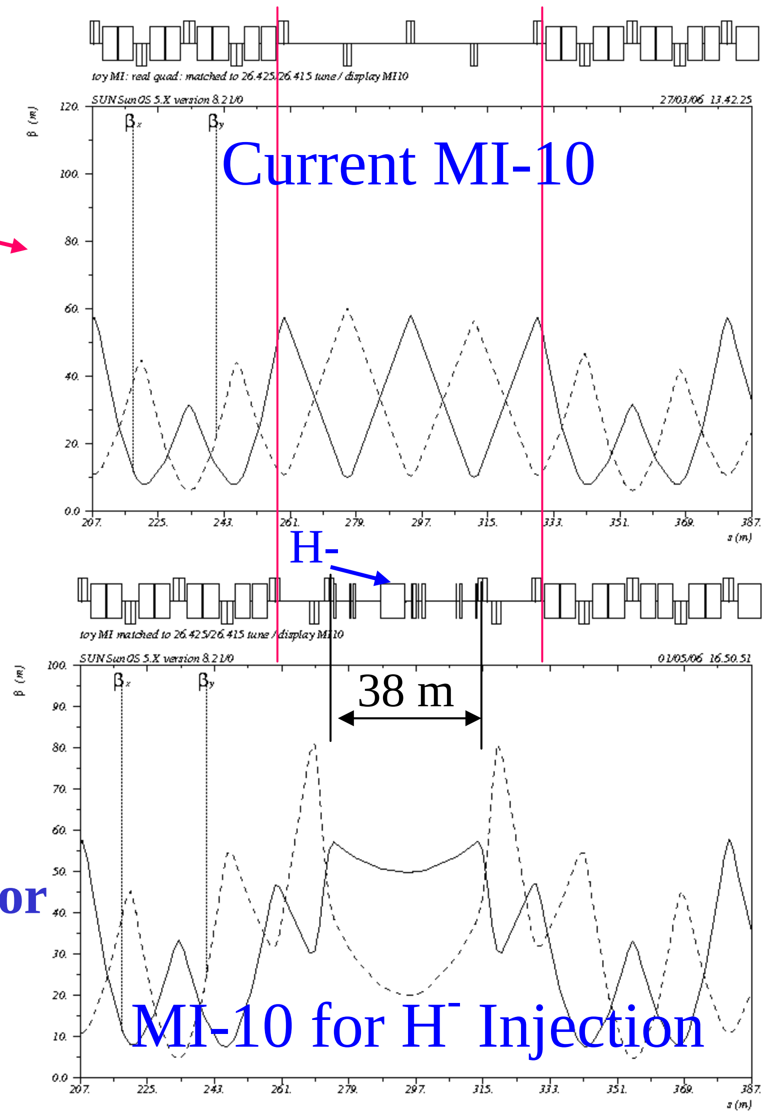
- **Build upon previous design work by W. Chou, A. Drozhdin, and others.**
- **2004 Workshop-> concluded that the design parameters were valid & performance could be reliably extrapolated from current experience**
- **Produce a conceptual design which addresses**
  - the relevant technical issues (such as control of stripping losses in transport, collimation design, un-controlled losses during injection, foil issues (material, thickness, environment), longitudinal injection dynamics, and magnetic designs.
- **Review the conceptual design to uncover any technical risks/design issues**
  - Address these issues folding in new or updated information-> REVISE DESIGN
- **Detail device design**
- **Produce final design document with cost estimate**
- **Other Steps to assure a successful Design**
  - Collaboration with BNL
    - Review of current conceptual Design
    - Optimization of Foil-stripping Injection system
    - (Design & fabrication of Laser profile monitor system)
  - Additional system reviews as necessary
  - Learn from SNS experience (energy jitter, collimation success, foil & laser stripping)
  - Utilize expertise at FNAL from Accelerator, Technical, and Particle Phys. Div.

MI H- Injection System – Technical Issues

- **Main Injector lattice modifications**
- **Design Concepts**
- **Optimization of Injection Layout**
- **Longitudinal Dynamics**
- **Detailed Design of Injection Components**
- **Injection Absorber Design**

MI H- Injection System (MI modifications)

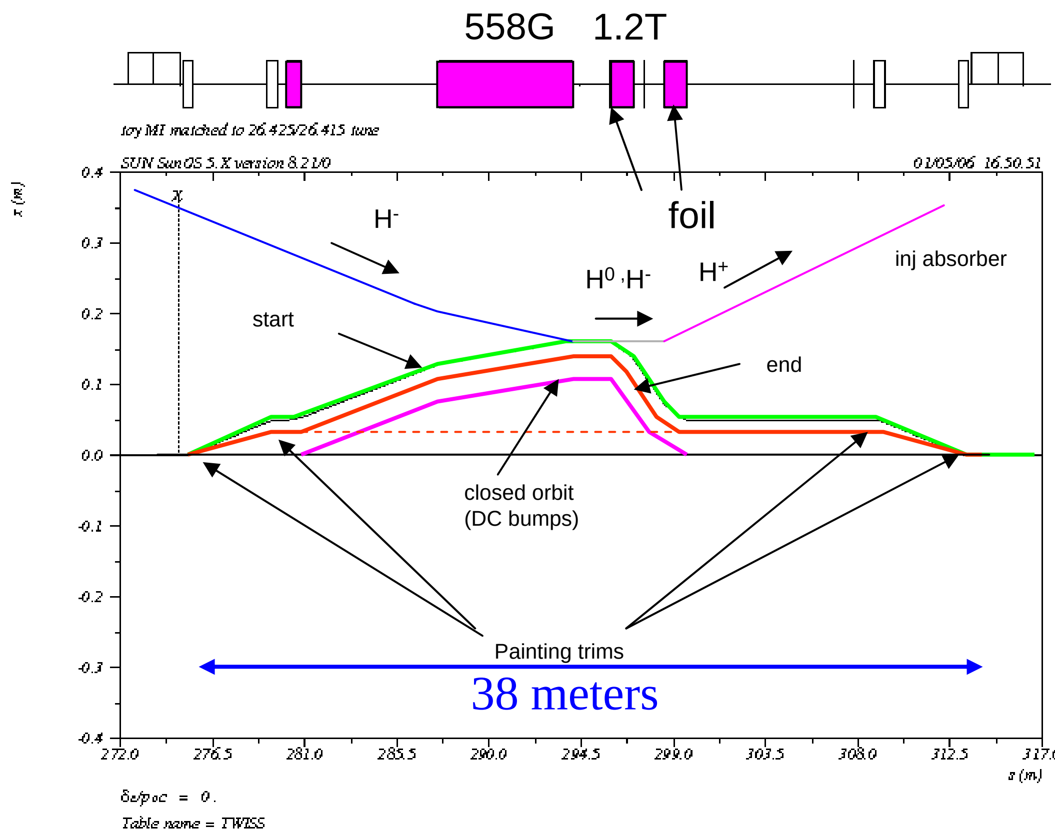




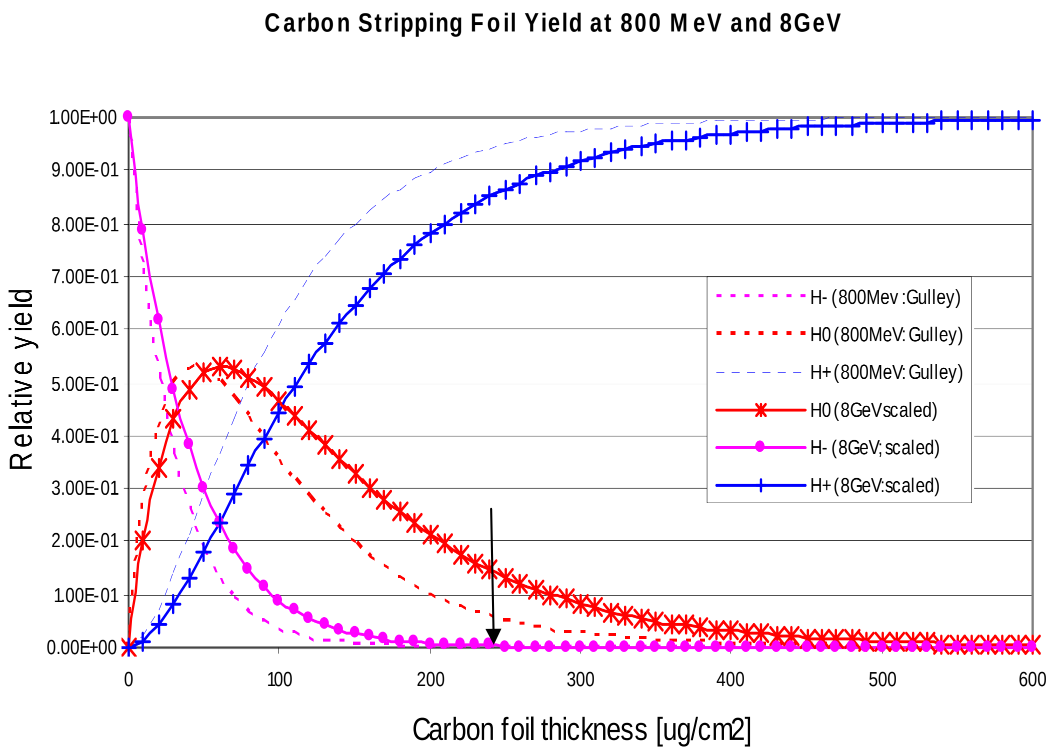
- **Flexible beta at foil**
- **Zero (Small) Dispersion in straight**
- **6 new quad circuits**
- **Power IQC/IQD trim coils in reminder of ring (with QF & QD) for tune control ->MTF measurements**
- **Minimal beta function distortion**

MI H- Injection System – Design Concepts

- **Fixed Chicane bump**
- **Phase space painting**
- **Flexible injection optics in transport and ring**
- **Zero (small) dispersion in ring and <u>transport line</u>**
- **Parallel beams in ring and transport line @ foil (α = 0)**
- **HB3 dipole separates H^+, H0**
- **Utilize HB3 fringe field**
  - for prompt conversion of excited H0 (n>=2) to protons (foil on rising field)
  - Lorentz stripping of H- missing foil (lifetime ~E-11 s)
- **Modification of MI**
  - Allowed this design to proceed



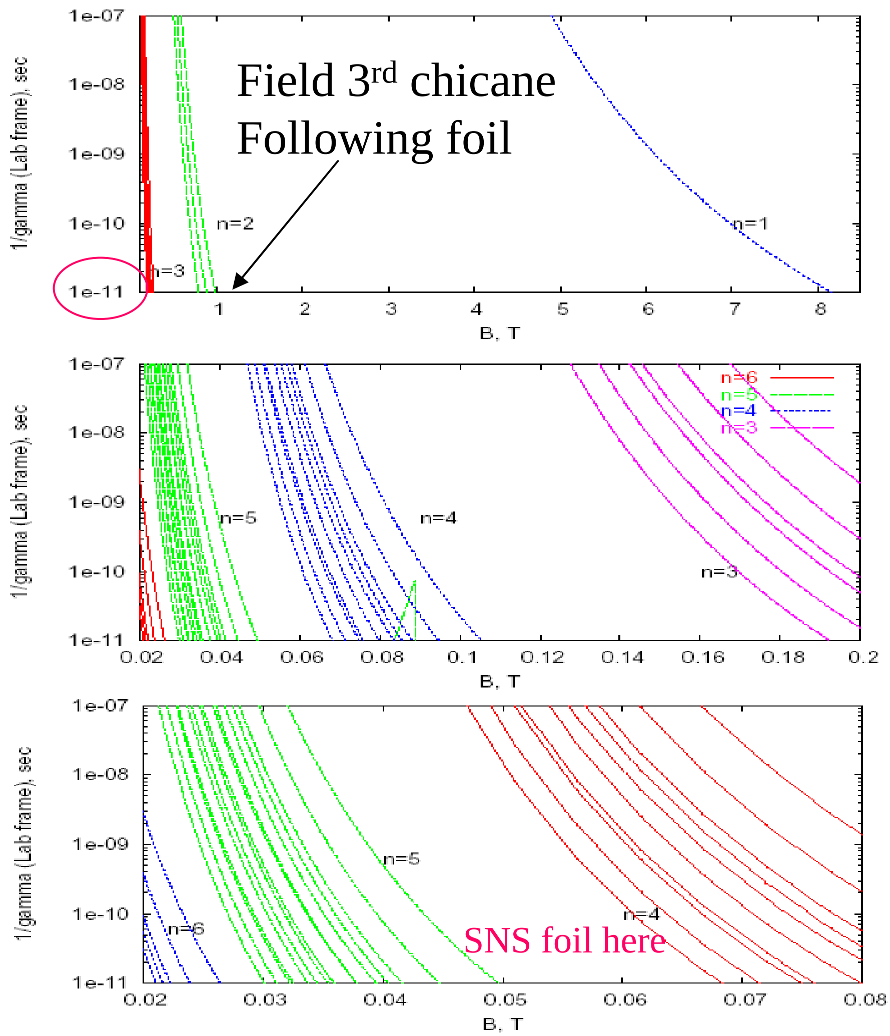
Production H^0 and H^- by Stripping Foil



- 800 MeV data reported by Gulley, et.al scaled to 8 GeV by β^{-2}.
- This scaling matches data from FNAL @ 200 MeV
- Red curve probability of stripping to state n=1,2.
- Relative yield of n>=3 much smaller
- Mohagheghi, et.al. resolved relative yield for 800MeV between n=1 and 2 as 28 and 130, respectivly.
- Implies at 250 ug/cm2
  - 86% protons
  - 11% H0(n=2)->strip to H+
  - 03% H0(n=1)-> to absorber

- Investigate additional measurements at 400 MeV & > 800 MeV to verify energy scaling and n=1,2 relative yields
  - FNAL (?) SNS Data (?)
  - BNL experiments

Use of End Field for Control of Excited States



- **Minimize probability for excited states being stripped outside the acceptance of the MI by downstream magnetic field -> leads to uncontrolled loss**
- **Data for lifetime of Stark states of 8 Gev H0 as a function of magnetic field corresponding to its rest frame electric field see by the atom.**
- **Calculations for 8 GeV were done by W.Chou, Alexandr Drozhdin and presented at the 2004 Workshop**
- **Path length for 1E-11 sec is approx 3 mm in lab frame**
- **For 2” fringe field -> 23.6T/m gradient -> $\Delta\theta$ ~7μr**
  - Requires careful design of chicane magnet end fields

MI H- Injection System- Optimization

- **Optimization of Foil-Stripping Injection System to maximize stripping efficiency and foil lifetime and minimize uncontrolled losses**
  - Lattice functions of circulating and injected beam
  - Foil material, thickness, and support structure
  - Position / orientation of foil in Chicane #3 fringe field
  - Phase space painting strategies
- **BNL Collaboration to provide assistance**
- **Utilize tracking program STRUCT (FNAL) and ORBIT (SNS implementation) for optimization**
- **Goal is to ultimately perform an end-to-end simulation with all known effects and errors (multiple codes)**

MI H- Injection System- Longitudinal Dynamics

- **Specifications on energy/phase jitter, excitation errors, etc. are defined by MI requirements**
  - 325 Mhz chopper key to pseudo-synchronous transfers
    - Roughly 2 out of every six 325 Mhz bunches chopped
    - Turn by turn longitudinal distribution evolution
  - Initial ESME simulations with two RF freq systems included uniform distribution with space charge (Phil Yoon) 100% capture at 270 turns with PD bunch intensities
  - Ultimate ESME simulations must include 325 Mhz micro-bunch structure in MI 52.8Mhz bucket AND include space charge, beam loading, longitudinal impedances, instabilities, longitudinal painting, etc.
  - Simulations are on-going
  - Results feed back into specifications for T.L. de-buncher cavity
  - Data from SNS energy/phase jitter to be used for confirmation

MI H- Injection System- Design of Injection Components

- **Chicane dipole magnetic design (B~1.2T)**
  - Wide aperture, gap consistent with remainder of MI (i.e. 2 inches)
  - End field shape and gradient important
  - Generate detailed field specifications for each magnet
  - 3D model
- **Injection kicker dipole (ring & beam line)**
  - Pure dipole (~2kG-m) , 1kHz bandwidth
- **Foil changer unit**
- **Electron catcher**
- **Status and strategy**
  - Current design is conceptual (with basic param: l, w ,g , B, end field, etc)
  - BNL Review of transfer line and injection conceptual design
  - As injection system matures, move into detailed magnetic design (2&3D)
  - Mechanical design and construction details

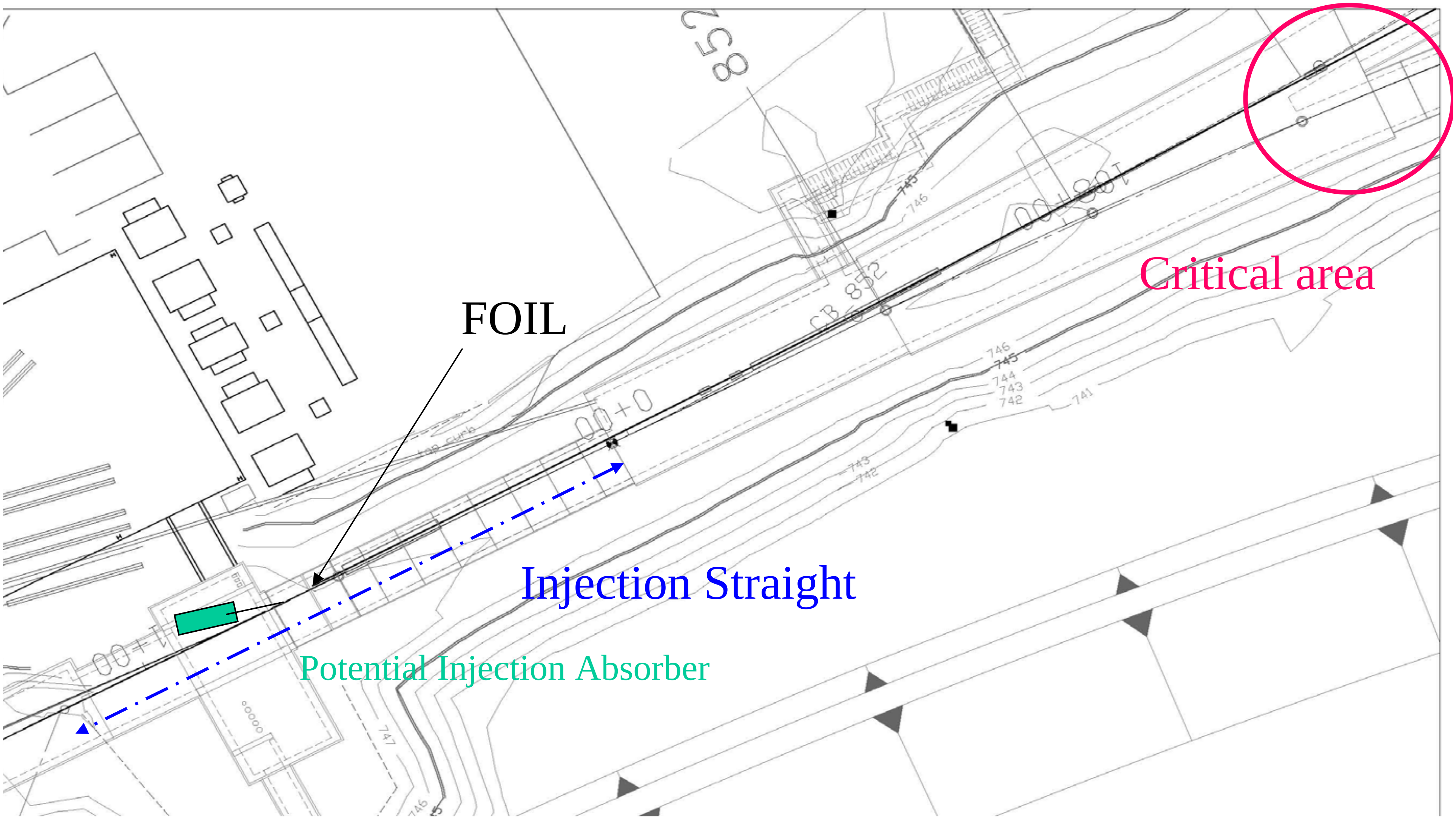
MI H- Injection System- Injection Absorber Design

- **Specifications for beam power and shielding efficiency**
  - Beams doc 2187 (power and Radiation Safety Guidelines)
- **Shielding design (design underway)**
  - Shielding materials (how compact: internal or external to tunnel)
  - Use MARS14 code for full scale Monte Carlo and e-m shower simulations in absorber, lattice elements, shielding, tunnel, and surrounding soil
- **Mechanical Design (not yet started)**
  - External shielding (based upon above design)
  - Corebox
    - Thermal considerations (cooling)
    - Stress wave considerations
    - Use ANSYS for detailed thermal and stress analysis
- **Utilize FNAL Energy Deposition Group for shield design calculations**
- **Use experience from MI abort core box design, SNS absorber designs**
- **Utilize FNAL engineers with ANSYS and absorber design experience in mechanical design**

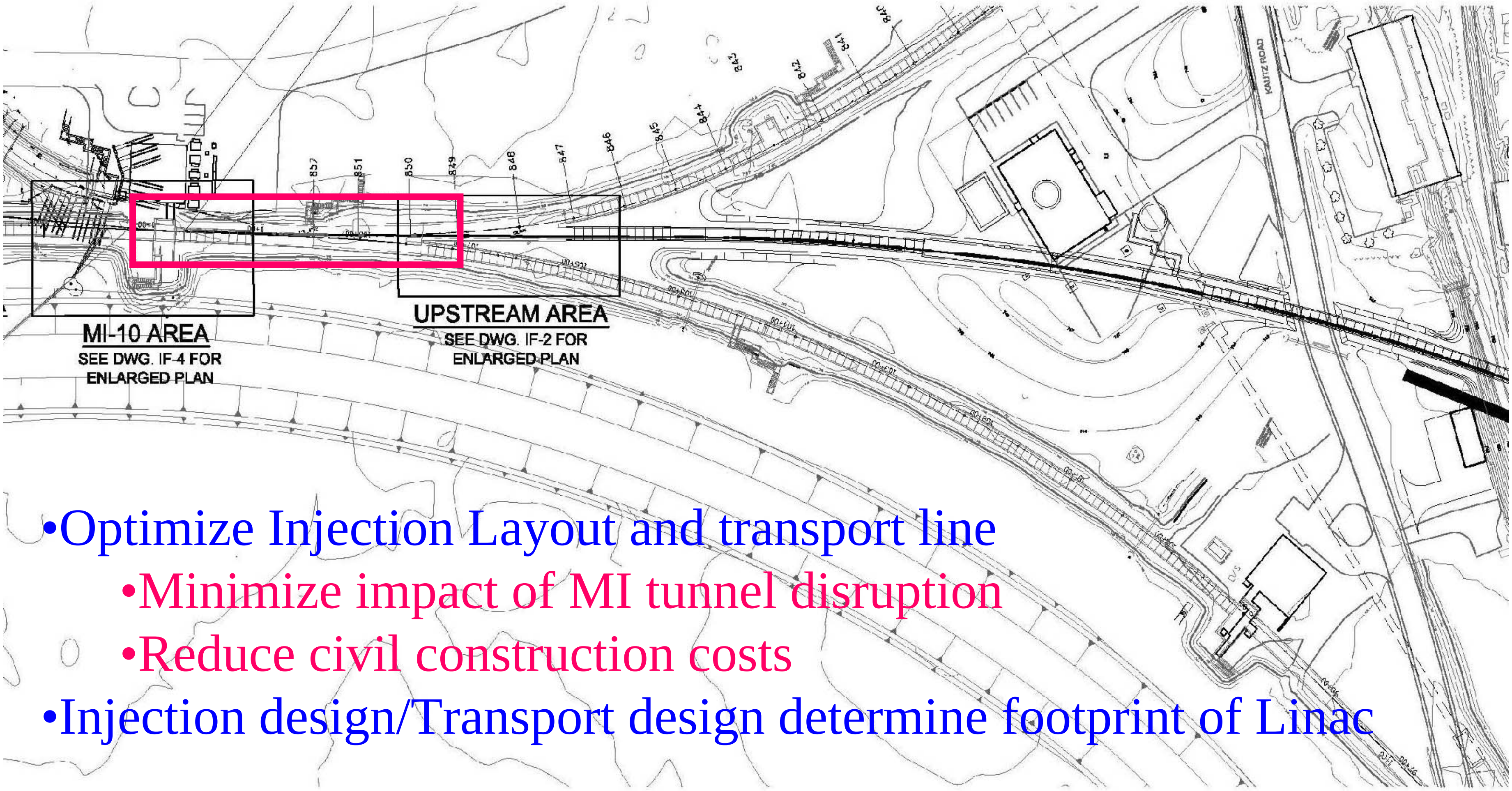
CONCLUSIONS

- **Conceptual Design is maturing with critical parts moving forward so that major civil construction issues may be resolved.**
- **BNL Collaboration moving forward to:**
  - Review current conceptual design
  - Aid in optimization of foil-stripping injection
  - Investigate the potential for future stripping experiments at energies of up to 2.5GeV
  - Produce a "laser profile monitor" for Meson test facility
- **Although the design has developed substantially since the 2004 Workshop, the conclusions remain that although the injection design is not trivial, no fatal problems have been uncovered.**

Interface with Main Injector



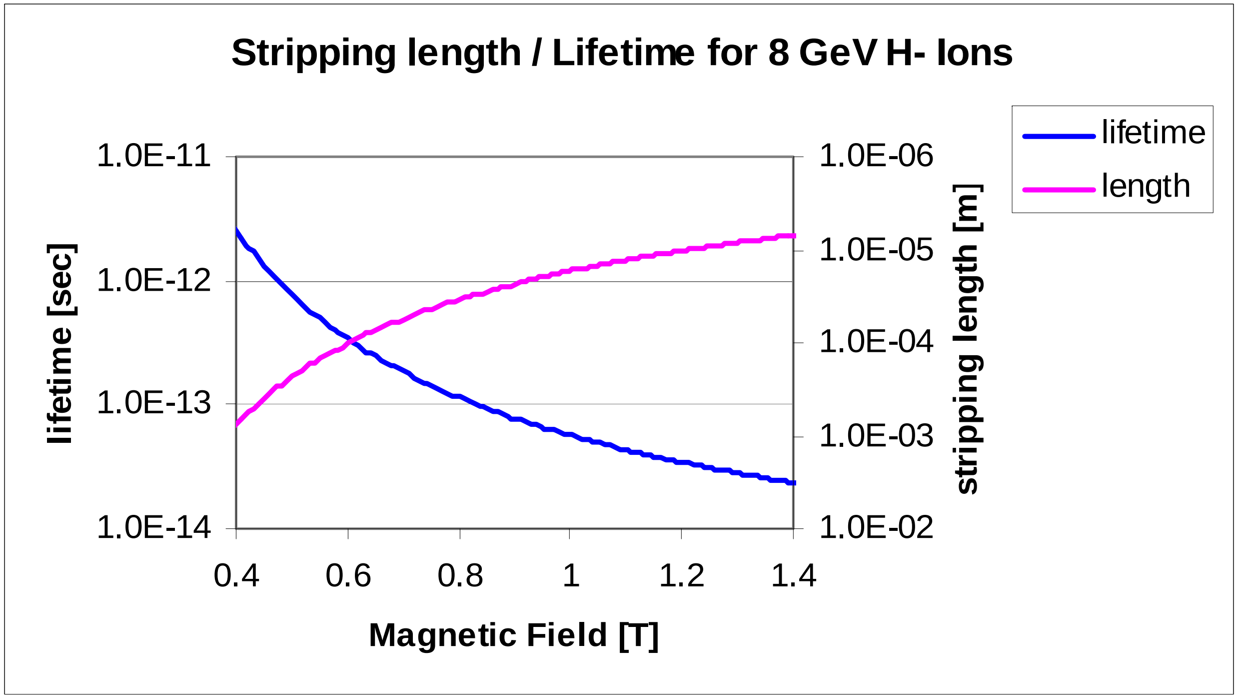
Civil Construction



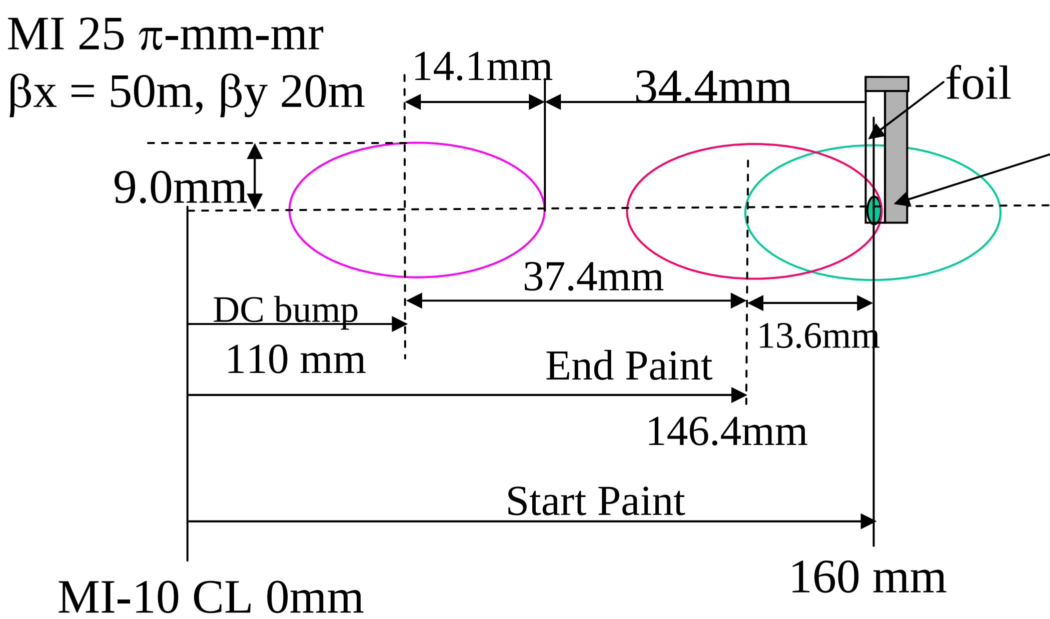
- Optimize Injection Layout and transport line
    - Minimize impact of MI tunnel disruption
    - Reduce civil construction costs
- Injection design/Transport design determine footprint of Linac

PLAN - MAIN INJECTOR INTERFACE REGION

Lorentz stripping in Chicane



Painting Geometry

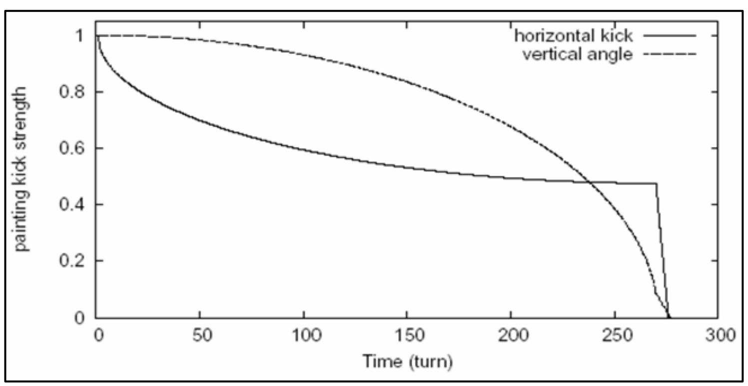


Linac 1.5 π-mm-mr
βx= 10m, βy = 20m
3σy +/- 2.1mm
3σx +/- 1.5mm

$$B = B_0\left[C1 + C2\left[1 - \sqrt{\frac{2N}{M} - \left(\frac{N}{M}\right)^2}\right]\right] \qquad N<M$$

$$B = B_0\left[C1 - \frac{N-M}{Q/C1}\right]$$

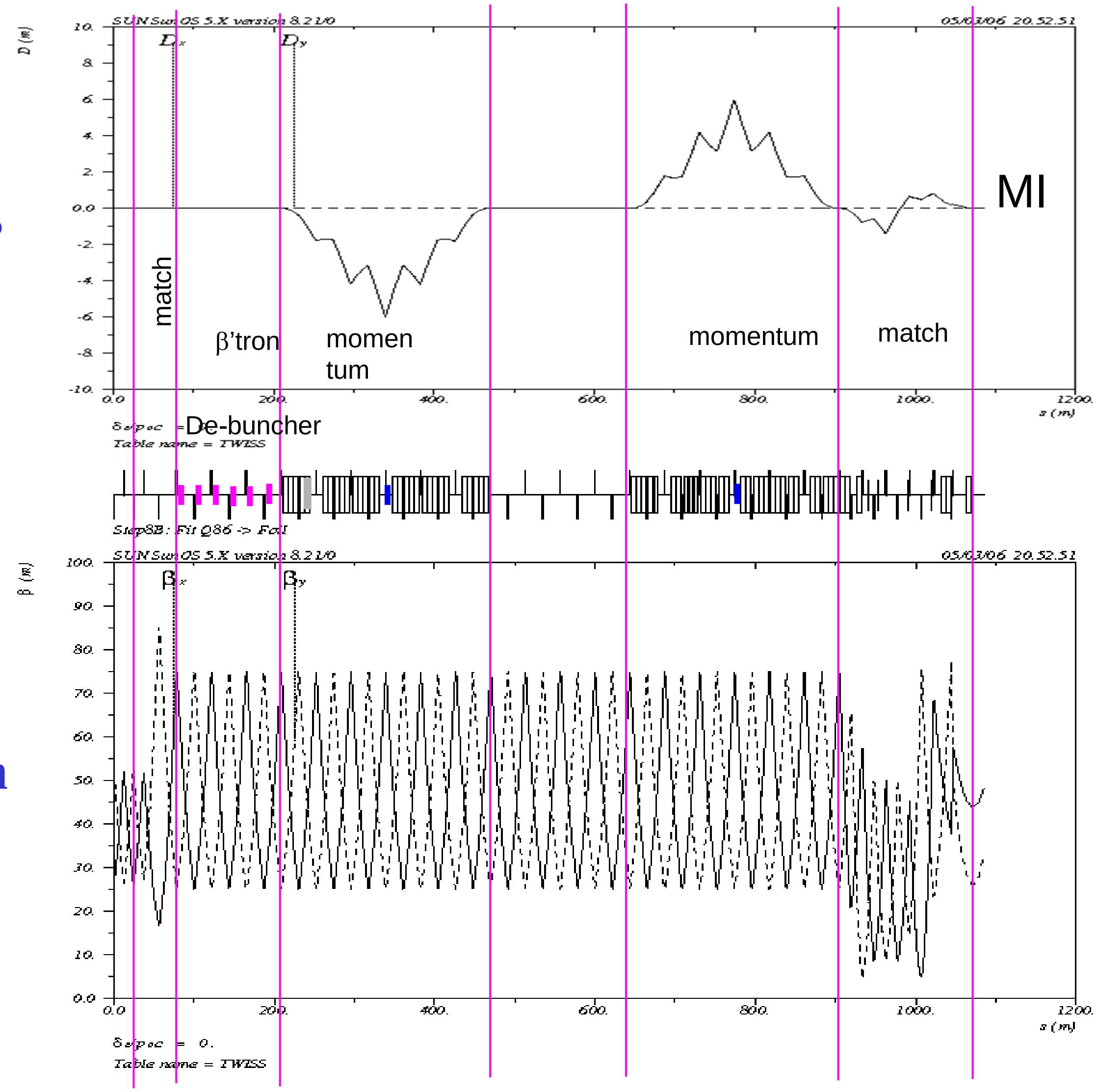
C1= removal/total offset
C2 = paint dist/total offset
M = number of painting turns
N = turn number
Q= number of turns to remove from foil



For this case:
C1= 13.6
C2=34.7
Total offset 50 mm

H- Transport Line – Current Status

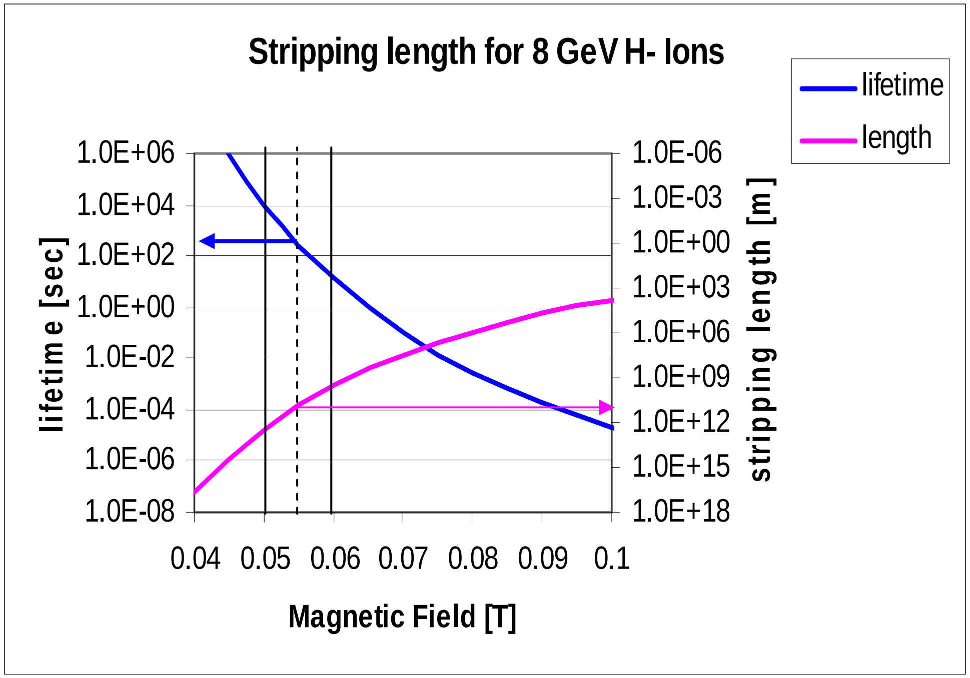
- **Footprint determined by MI Injection design**
- **60 degree FODO lattice**
- **2 achromatic bend sections for momentum collimation (550G) - civil constraint**
- **Straight for β'tron collimation**
- **Straight section for de-buncher/stretcher**
- **Achromatic matching into MI (wide tuning range in beta at foil, with alpha =0)**
- **Quad gradient +/- 10 kG/m -> 260 G @ 1"**
- **Aperture ratios 3σ/(w/2)**
  - Dipole: H 8.5/95 ,V 8.5/22
  - Quad: H&V 8.5/38



H- Transport Line- Technical Issues

- **Control of stripping losses in transport line (addressed in 2004 Workshop)**
  - Lorentz stripping (next slide) beam power loss ~0.0016 W/m (@134 kW)
  - Black body radiation (H. Bryant, C. Hill) ~0.11 W/m
    - preliminary design of cold beam tube shield -> 0.0001 W/m
      - elliptical Al extrusion to fit inside 2X4 rectangular beam tube (1.75”x3.75”)
      - Based on LHC cryostat shields cost ~ $30K-ish
  - Vacuum stripping @10-7 to be ~0.013 W/m -> 0.002W/m)
- **Collimation (transverse and longitudinal beam shaping & machine protection)**
  - Betatron (utilize clever foil stripping system developed for SNS)
    - Initial simulations-> collimator jaws set at 4σ
    - Revisit simulations (using STRUCT and ORBIT)
  - Momentum (review in-line absorber design)
  - Adjustable aperture for both foil and absorber
  - Detailed foil stripper and absorber designs have not yet begun (AD EDG)
- **Detail design of new transport magnets, vacuum system, instrumentation**
  - No major technical issues anticipated

Lorentz Stripping



- **Use expression from L. Scherk for rest frame lifetime of H- in applied magnetic field**
- **Calculate lab frame lifetime ($\beta\gamma\tau$) and stripping length ($\beta\gamma c\tau$)**
- **Basic eq. not in question**

- **At dipole field of 550 G Loss rate ~7.5E-9 /m**
  - With 1.54E14/1.5 sec ~8E5 particles/m/s 0.001 W/m (comparable to vacuum with cold beam tube liner)
- **At dipole field of 500 G Loss rate ~ 3.8E-10 /m**
  - With 1.54E15/1.5 sec ~ 3.9E4 particles/m/s 0.00005 W/m